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An Aluminum/Steel Endframe Design for an Off-Axis Detector Module

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Introduction

A design is presented for an 8x8x28 ft 43-ton detector module based on the ISO shipping container concept[(1)] in which stacking forces are withstood solely by stout posts at each module corner. Composite metal plate and particle board corner posts are used to permit stacking up to 7-on-1 high. Ten RPC modules (consisting of a ½ inch thick chamber assembly sandwiched between two two-inch thick layers of particle board) are attached to the endwalls by thin ribs that reinforce the structural angle which bears the vertical load of the remaining absorbers. Two additional RPC modules are only 3.5 inches thick, and attach directly to the sidewall absorbers, serving no structural purpose.

This RPC module assembly, shown in Fig. 1, forms a toaster-like box weighing approximately 23 tons, into which the remaining absorbers are inserted. The completed detector modules are stacked in an array two across and eight high. They are oriented such that the endframe that lies in the center of the detector array is aluminum, and the endframe on the perimeter is steel, as indicated in Fig. 2. All module services (gas, power, data) are routed out through the steel endframe of the module.

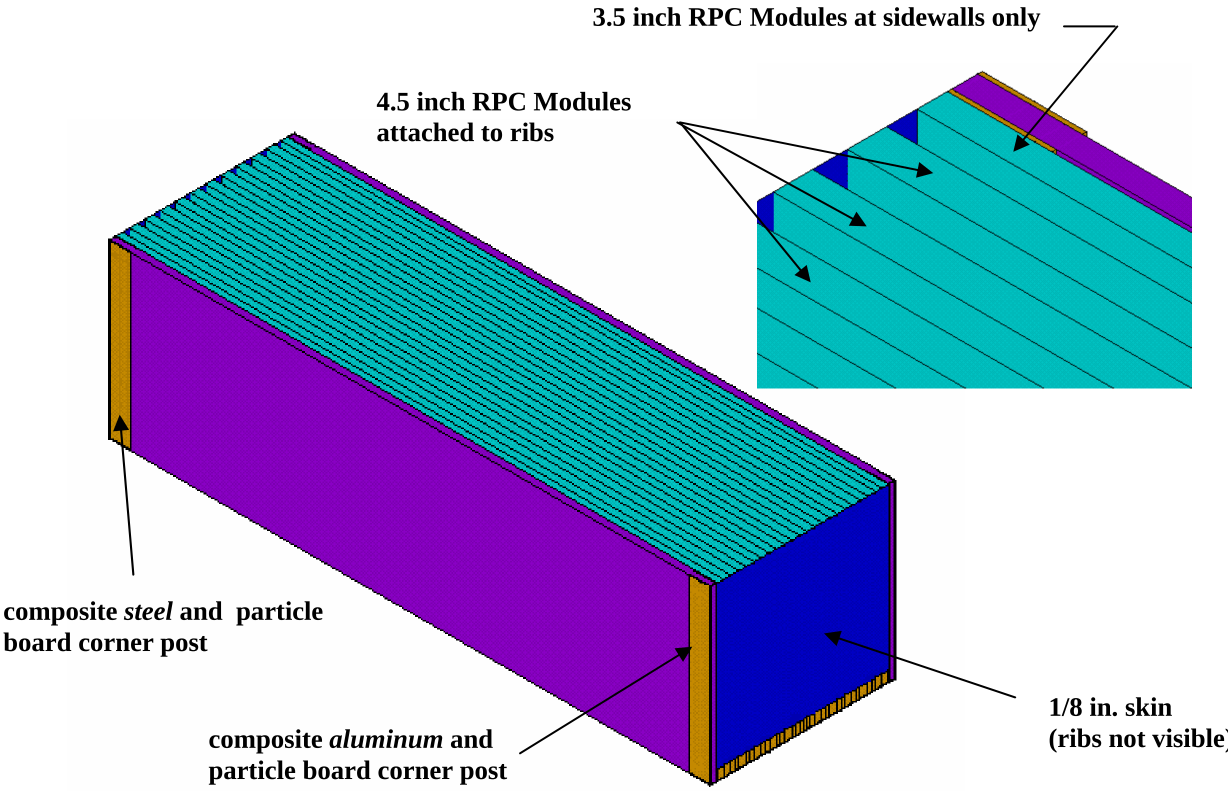

Figure 1. RPC Module Assembly

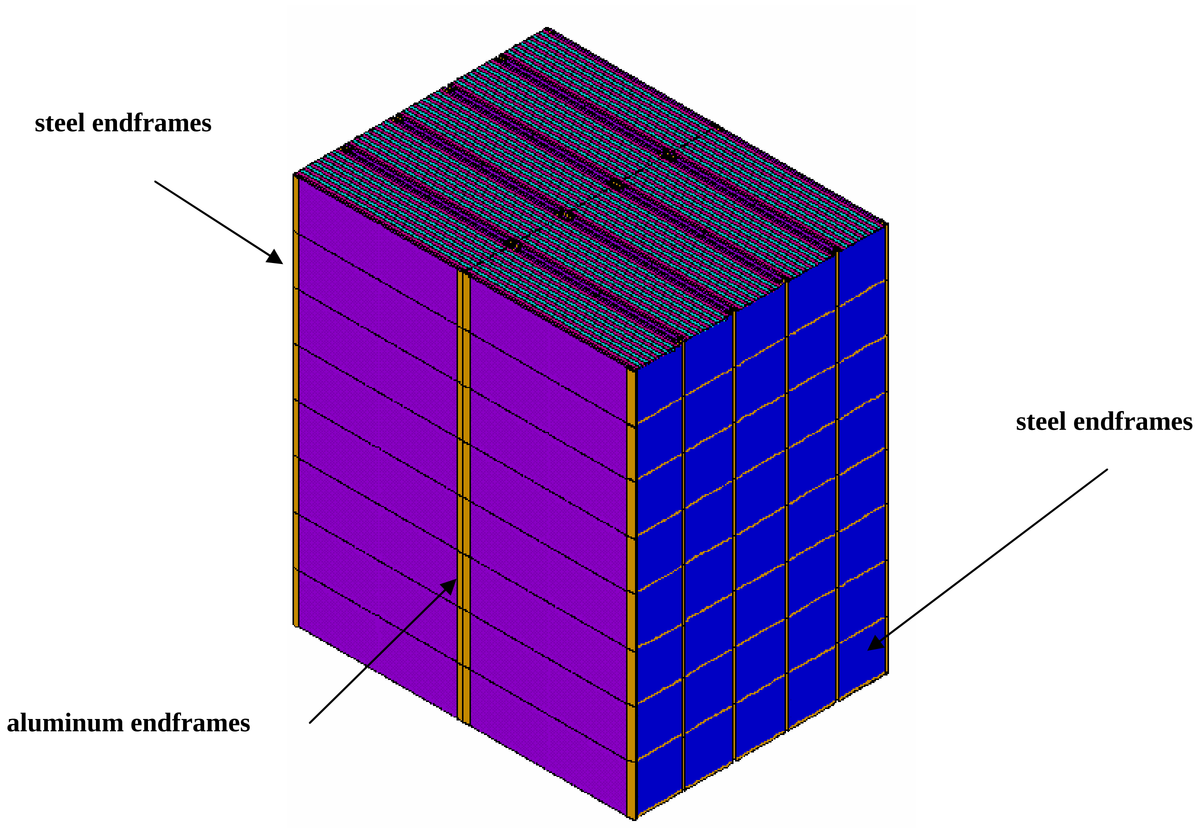

Figure 2. Portion of Detector Module Array

The Endframe Design

Details of the endframes are shown in Fig. 2. Each composite corner post is formed with a 3-inch particle board absorber sandwiched between two 12 inch wide by 0.5 in. thick aluminum plates (or two 0.375 in. thick steel plates). Between the corner posts at the bottom a 6x6x0.5 inch aluminum angle is attached on one end; a 6x6x0.375 inch steel angle is used on the other. This angle provides the bearing support for the components of the module. It is stiffened with 10 0.125 inch thick ribs, welded to the bottom leg of the angle, and to a 0.125 inch thick skin which covers the endwall. These ribs are stiffened by attaching them to one of the one-inch particle board absorbers on the side of the 4.5 inch thick RPC module, as shown in Fig. 3.

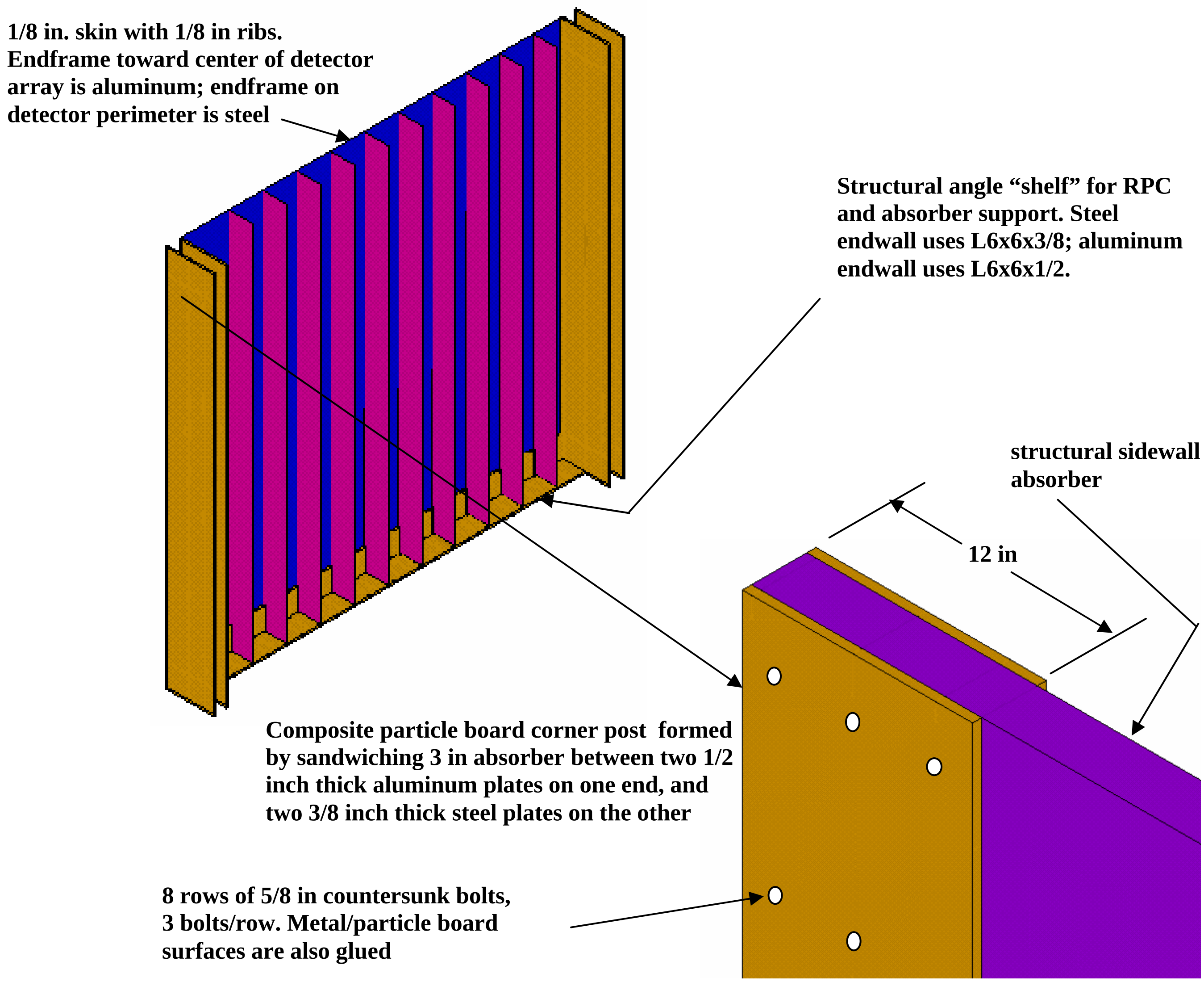

Figure 2. Endframe Assembly

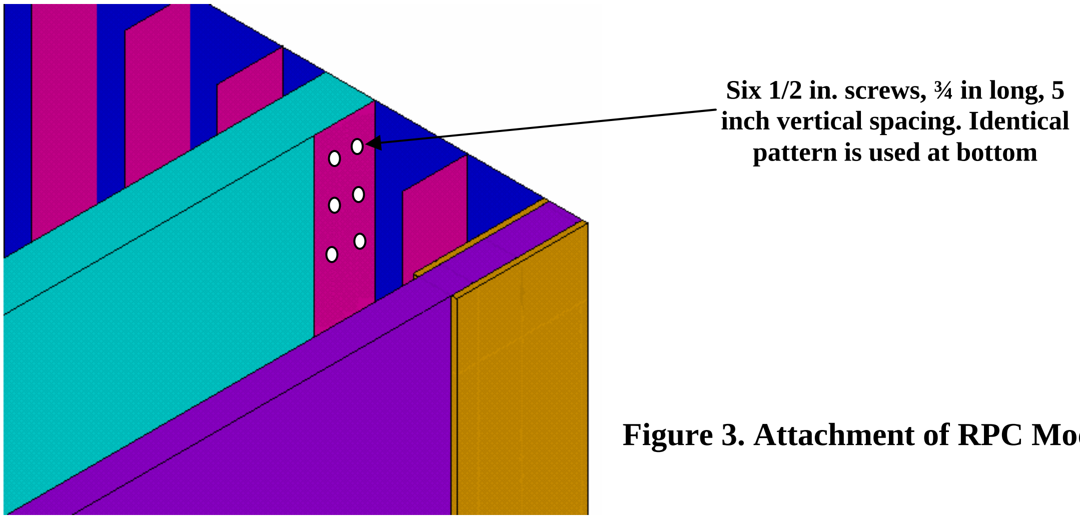

Figure 3. Attachment of RPC Module to Rib

The top and bottom of the composite corner post will contain solid aluminum blocks which act as corner fittings for registering the modules during stacking. These corner fittings are shown in Fig. 4. A 1.5 in. diameter pin, 1.25 inches long, is threaded into a steel insert in the top corner fitting, and mates with a hole in the bottom corner fitting of the module above it. For lifting, the pin is removed, and a lifting lug threaded into place. The steel insert is installed from the underside of the top corner fitting, and is designed such that all forces between the aluminum and steel are taken in bearing on the insert shoulder, i.e., there is no reliance on threads in the aluminum or interference fits to withstand the lifting loads.

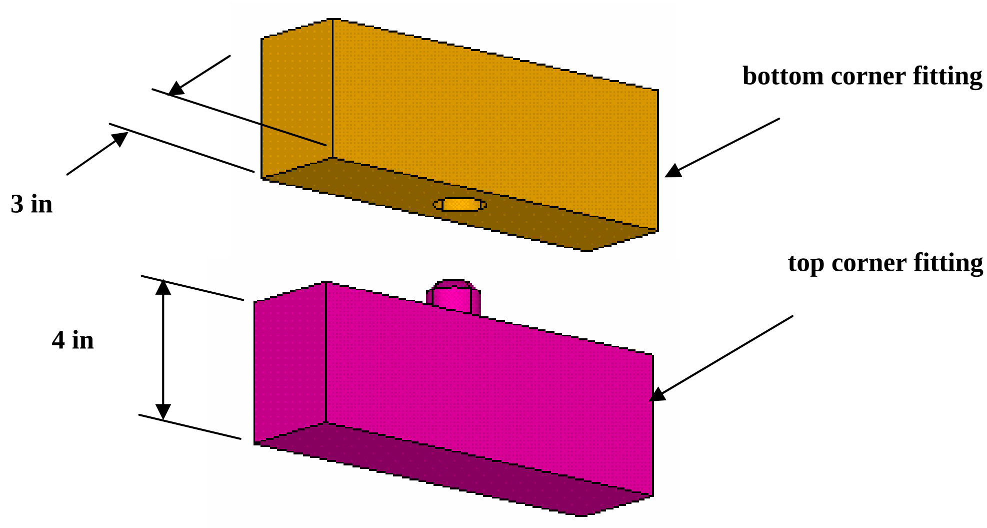

Figure 4. Module Corner Fittings (these are embedded in the top and bottom four inches of composite column)

When the structural box is complete, the four-inch thick non-structural absorber panels can be slid into place, as shown in Fig. 5.

The stacked modules will have a ½ inch gap between each module vertically (i.e., the corner posts are each ½ in longer than the vertical height of the absorber, leaving ¼ in. top and bottom clearance per module, or ½ inch between stacked modules).

If the absorbers are notched to lie on the top surface of the vertical angle leg, in near contact with the 1/8 in. endwall skin, and if the modules can be stacked side-by-side with minimal clearance, the horizontal gap between modules will be the sum of the two endwall skin thicknesses, or ¼ inch.

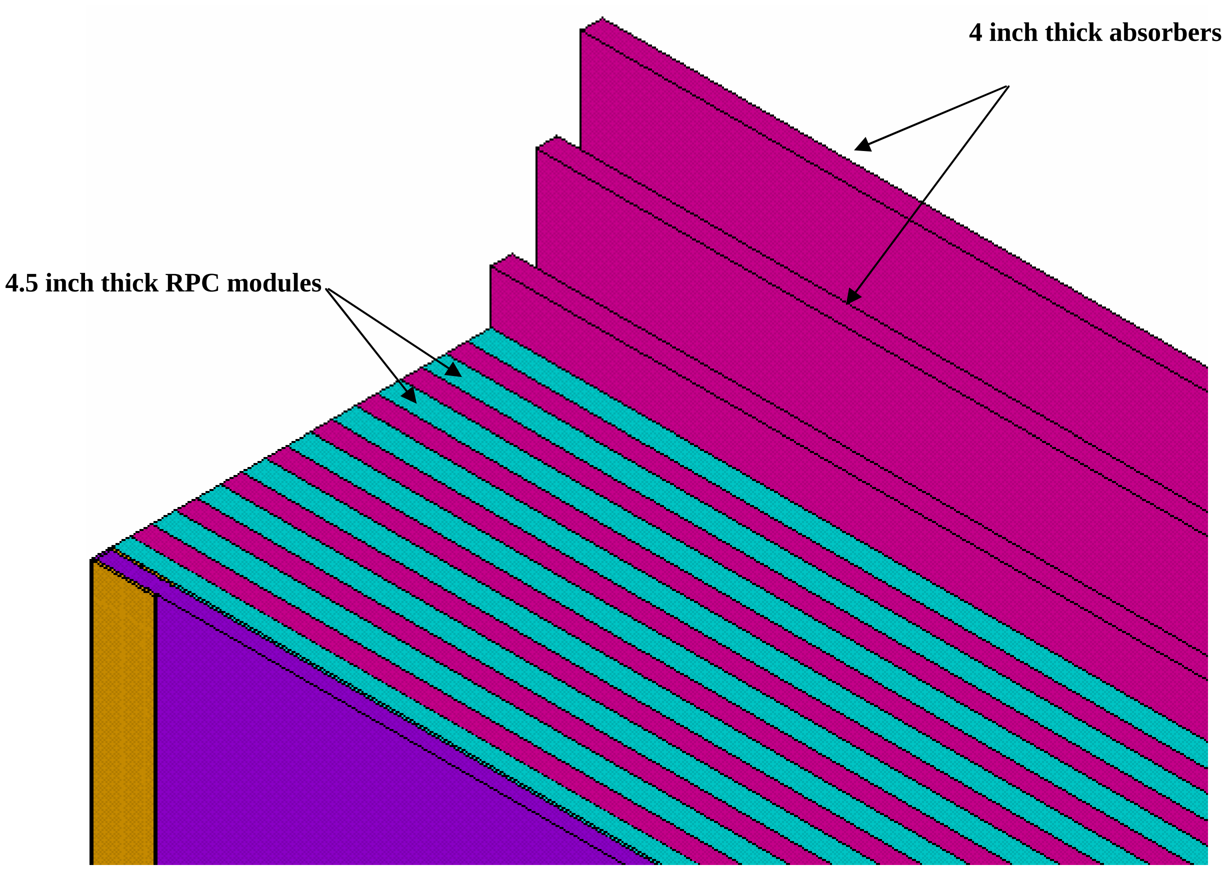

Figure 5. Non-structural absorber inserted into box

Summary of Stress Analysis

Corner Post Buckling under Stacking Loads

The pinned-end Euler buckling load for a column is

$$P_{cr} = \pi^2 EI/l^2$$

where: P_{cr} = buckling load
E = Young's modulus of aluminum = 10e6 psi (Al), 30e6 psi (Steel)
I = minimum moment of inertia of column = 38.5 in^4(Al), 25.7 in^4 (Steel)
l = length of column = 96 in

Substituting into the equation gives P_{cr} = 412,000 lbs and 826,000 lbs for the composite corner aluminum and steel corner posts, respectively.

The weight of a single module is approximately 43 tons. Therefore, the load on a single corner post in a 7-on-1 stack is (43*7*2000)/4 = 150,500 lbs. The composite corner posts will therefore have a safety factor of 2.7 and 5.5 on Euler pinned-end buckling, for the aluminum and steel, respectively. Given that the corner posts will have some rotational resistance (provided by the skin, and by interaction with the corner fittings of modules with which it mates), the actual safety factors will probably be higher.

Attachment of Absorber to Ribs

The RPC modules are attached to the ribs by screws which penetrate only the first 3/4 inch of the module absorber panel. The weight of the module is reacted by the structural angle shelf; analysis shows that the horizontal forces on the connection produce a large moment, but negligible net forces. Fig. 6 shows the moment applied to the RPC module through the rib by the attempts of the structural angle to rotate under the module and absorber weight.

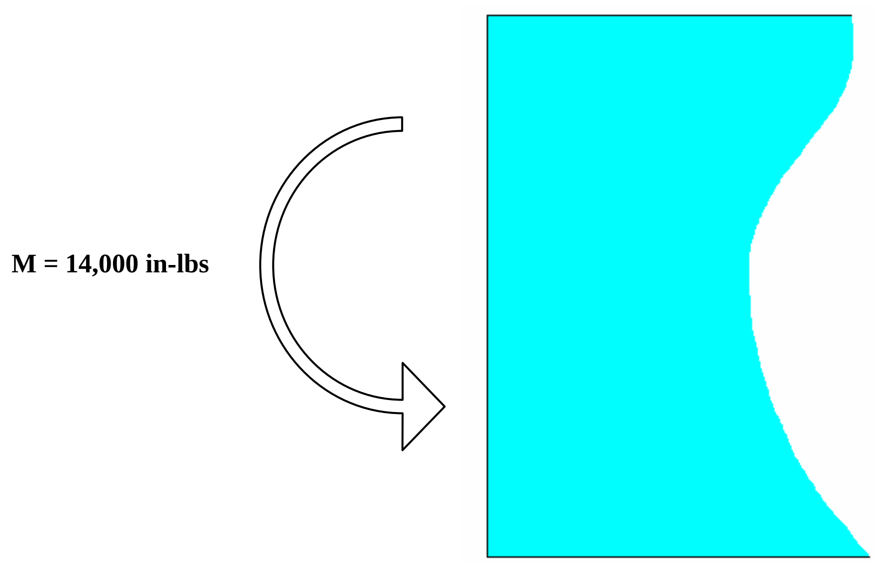

Figure 6. Moment on RPC Module at Connection with Rib

If the maximum fastener bearing stress in the absorber is limited to 150 psi, then a 0.5 inch diameter screw passing through 0.75 inches of a one-inch thick absorber panel can safely carry a force of F = (0.5)(0.75)(150) = 56 lbs. It can be shown that twelve such fasteners, spaced vertically 5 inches apart in the top and bottom 15 inches of RPC/rib contact, are capable of carrying the loads shown in Fig. 6 with a safety factor of 1.7. For such a configuration, the maximum fastener load is 33 lbs, and the maximum bearing stress on the particle board absorber is 88 psi.

Stresses and Deflections in Bottom Angle

The most critical welds in the endframe are those between the 1/8 inch thick aluminum rib and the horizontal leg of the 6x6x0.5 aluminum angle. 6061-T6 aluminum loses strength in the region of a weld, so a reduction of working stress must be applied.

For this location in this structure, the maximum stress in the region of the weld is limited to 16 ksi. The finite element model for this region shows that the maximum linearized weld stress (disregarding peak stresses) is 6 ksi, as indicated in Fig. 7. The corresponding stress in the steel angle is 9 ksi.

Maximum deflection of the angle occurs midway between two ribs, and is 0.029 inches for the aluminum angle, and 0.016 inches for the steel angle. Given that the total clearance between modules is 0.5 inches, this should present no problems.

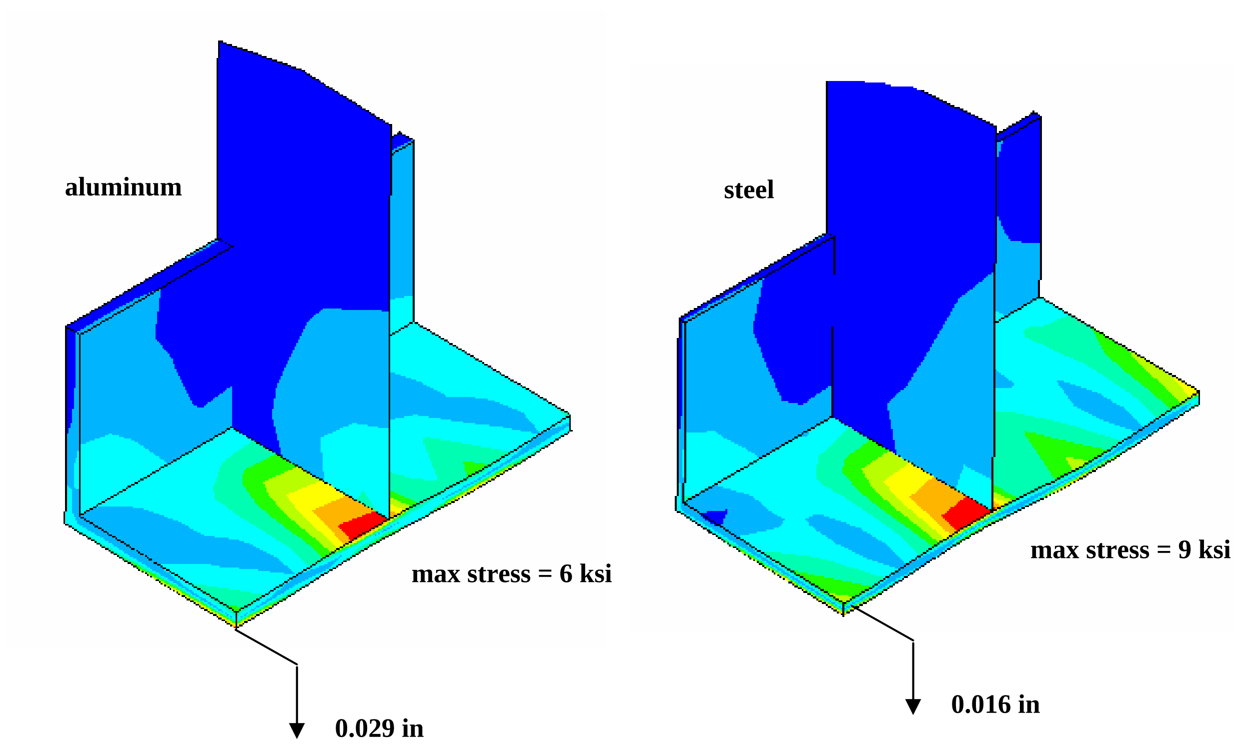

Figure 7. Weld Stress and Angle Deflection in Endframes

Three Point Support

The module is designed to handled carefully, insuring at all times that all four corners are supported in a horizontal plane. However, there may be circumstances in which some out-of-plane movement of one corner cannot be avoided. It is important to understand how far a corner might drop or rise without compromising the structure.

Analysis indicates that the force required to lift one corner of the module a distance of two inches vertically is about 17000 lbs. The highest absorber stresses are developed at the connections between the outer 3 inch sidewall absorber and the aluminum plates of the composite corner post near the lifted corner, as shown in Fig. 8.

The attachment of the structural absorbers to the aluminum plates of the corner posts are not fully detailed; However, the analysis shows that the connection at this point must resist a force of 500 lbs spread over a cross sectional area of 3 in^2, for a nominal stress of less than 200 psi. Given that the rupture strength of particle board is approximately 1500 psi, it should be possible to design the connections such that a single corner of the module can be displaced out of plane by two inches without failure.

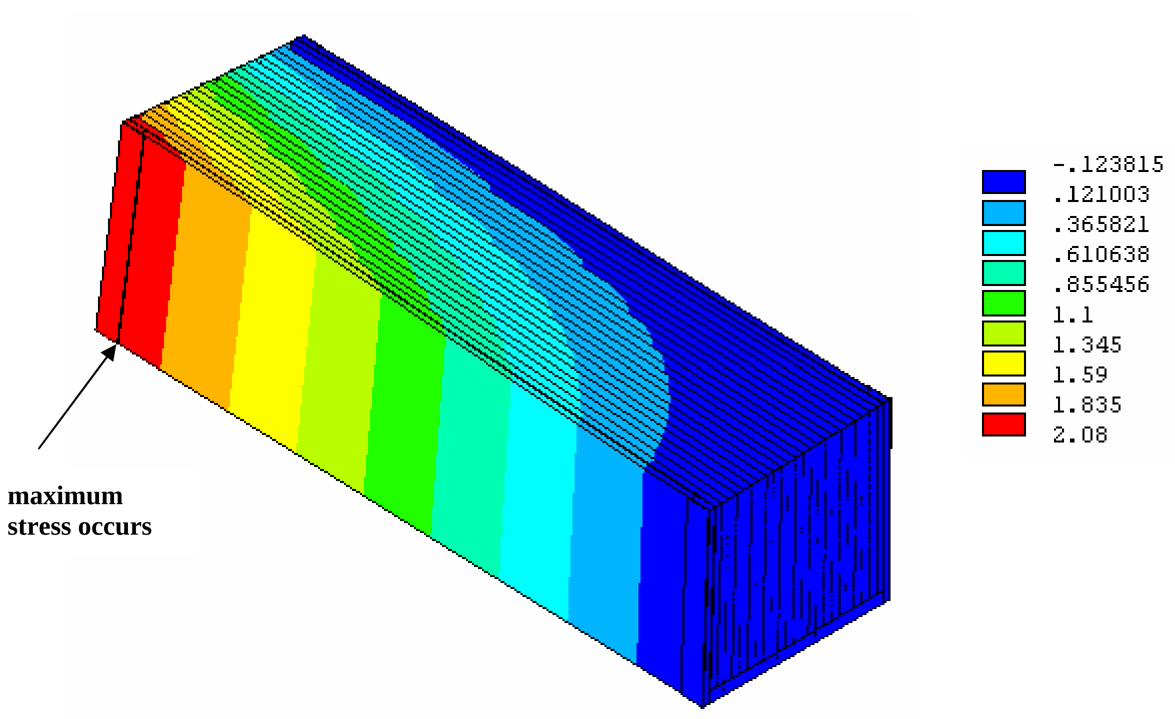

Figure 8. Deformed Shape of Module with Corner lifted 2 inches

Cable and Gas Routing

The horizontal and vertical readouts are gathered toward the top and one side of each RPC module, running through shallow channels in the module edge. Along the side, they are terminated in connectors covering several inches of the 96 inch long side. The gas piping will take a similar route, terminating in inlet and outlet connectors on the same side as the readouts.

The module is inserted in the endframe structure such that these connections will line up with penetrations in the skin of the steel endframe; i.e., the readouts and gas connections occur only on the steel side of the endframe structure, which by design lies on the periphery of the detector.

Reinforcement of the steel skins may be necessary to restore strength lost by the cutouts required for the RPC module connectors. This should present no special difficulties, since the amount of material in this region is not critical to the detector performance.

RPC Module ("Toaster") Assembly

This discussion covers the assembly of the RPC modules, structural sidewalls, and endframes into the RPC module assembly, or "toaster". The final assembly step – insertion of the remaining 20 tons of absorber panels – is not covered.

Also not covered is the building of the individual RPC modules. They are assumed to have been built and delivered to the RPC module assembly operation ready to be installed.

Structural Absorber Sidewall Assembly

The structural absorber sidewall assemblies consist of two 3-inch thick absorber panels, which are bolted to the endframes to form the sides of the module assembly, as well as the center of the composite columns. These panels are formed by gluing and screwing three 1-inch thick particle boards into a single unit.

A rigid fixture twenty-eight feet long and eight feet wide, grouted to the floor, will allow accurate stacking of the three boards. Individual boards as well as the completed three-board assembly will be handled by a vacuum lifting fixture. Glue will be applied between the boards, and in a final operation, a sparse pattern of screws will be used to hold the boards together as the glue sets.

A crew of three – one lead technician, and two technicians – might be expected to move three boards, apply glue to two interfaces with commercial paint rollers or sprayers, insert the screws with electric or pneumatic screw guns, and remove the assembly to a holding area in about one-half hour.

RPC Module Assembly

As the absorber sidewalls cure, the two endframes are lifted and set into fixtures which ensure the dimensions of the final toaster assembly. These fixtures are rigid weldments, leveled and adjusted and grouted to the floor. Their floor plates contain vertical pins which mate with the holes in the bottom corner fittings of each endframe. The top of the fixtures contains removable blocks which allow the frames to be inserted vertically into the fixture, and then secured by the blocks, which mate with the top corner fittings of the frame.

The first absorber sidewall is brought in from the side, as shown in Fig. 9. Glue is applied to the surfaces contacting the aluminum plates, and the sidewall is attached to the frames by 24 5/8 inch bolts through the aluminum plates. One of the 3.5 inch thick RPC modules is then inserted vertically, and screwed from the outside to this structural panel. The ten 4.5 inch thick RPC modules are then inserted vertically and attached by 12 screws to each rib, as shown in Fig. 10. The final 3.5 inch thick RPC panel is inserted vertically, and the final sidewall is brought in from the side and attached to the frame and the final RPC module, completing the "toaster "assembly of Fig. 11.

The 23 ton assembly is released from the fixtures, and moved with the module lifting fixture to make way for the next module.

Positioning the frames in their fixtures might take approximately 30 minutes (15 minutes per frame). The fourteen remaining components (12 RPC modules, and two structural absorber sidewalls), might be positioned and installed in about 30 minutes each. The toaster assembly would then take approximately 7.5 hours to build.

Adding the additional hour necessary for constructing the sidewalls brings the total "toaster" assembly construction time to 8.5 hours.

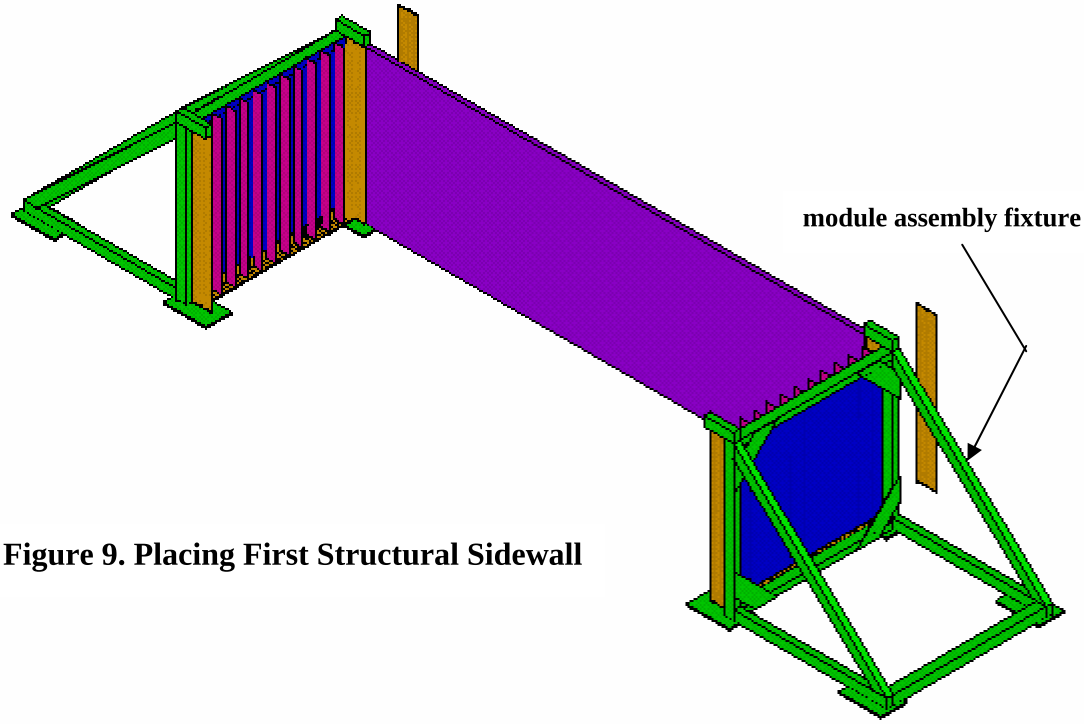

Figure 9. Placing First Structural Sidewall

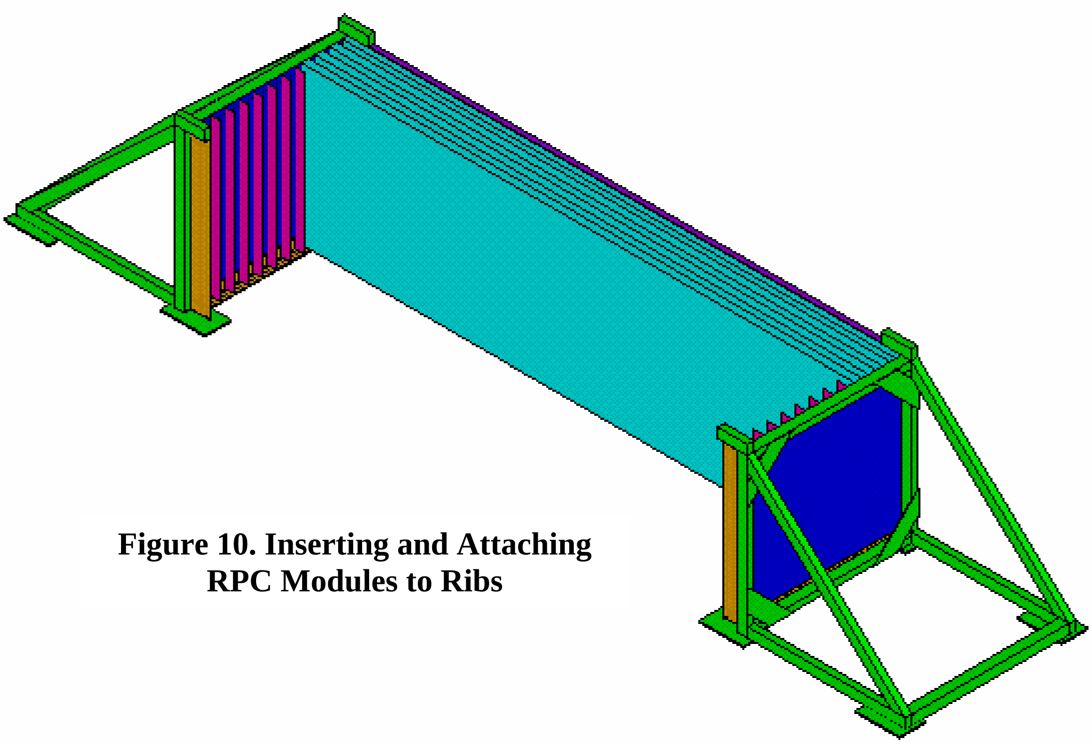

Figure 10. Inserting and Attaching RPC Modules to Ribs

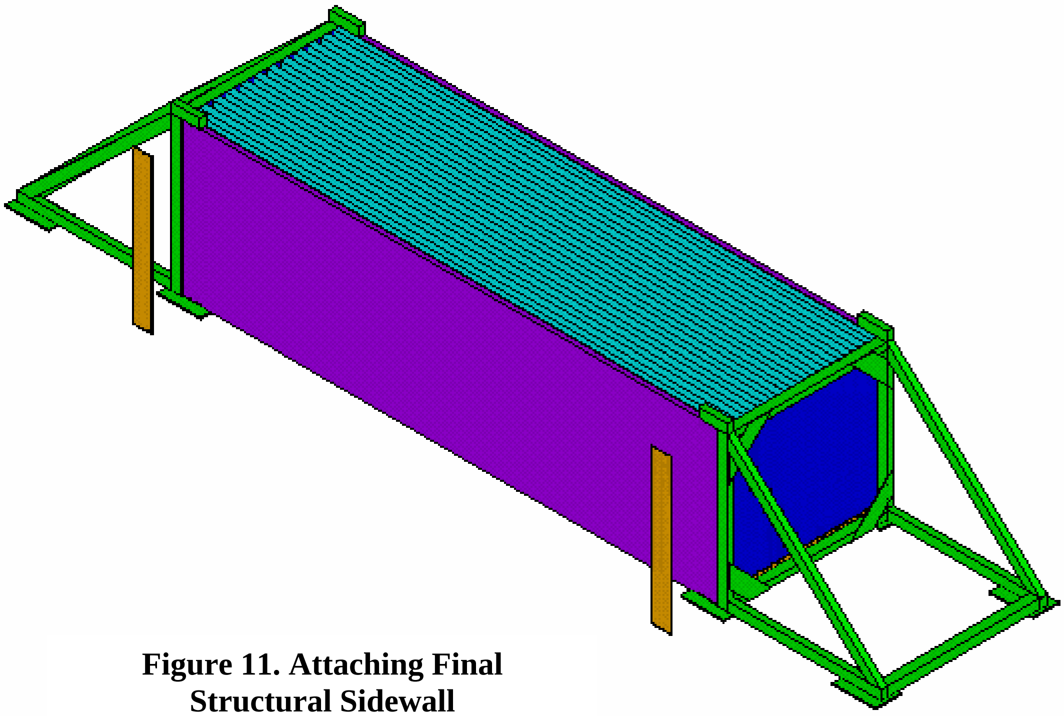

Figure 11. Attaching Final Structural Sidewall

Summary

The fixturing and component costs are summarized in Tables I and II. The assembly times are summarized in the task breakdown of Table III. Miscellaneous costs not tabulated are screw guns (two @ $500/each), and glue applicators. For the glue, paint rollers and pans could be used, but the large quantity of glue required for each interface (14 gallons) might argue for spray application.

The total fixturing cost, exclusive of installation, is $22,000. The total component cost/module is $3530. Total time to assemble one module is 8.5 hrs, using a crew of one lead technician, and two technicians.

Table I. Fixturing Costs

Fixture	Fabrication		Installation	
	Weight	Cost	Crew	Time
Structural Sidewall Assembly Fixture	4440 lbs	$6660	3 techs, 1 surveyor	7.5 hrs
Module Assembly Fixture	2500 lbs/end	$7500 (both ends)	3 techs, 1 surveyor	7.5 hrs
Module Lifting Fixture	5244 lbs	$7860	-	-
Vacuum Lifting Fixture for Particle Board	-	$18000	-	-

Table II. Component Costs

Component	Quantity	Cost/unit	Total Cost
Aluminum Endframe	1	$1330	$1330
Steel Endframe	1	$1390	$1390
Structural Particle Board	6 sheets	$88/sheet	$528.00
Glue	28 gal	$10.00/gal	$280.00
Screws	112	$.05/each	$2.80

Table III. Task Breakdown

Sub Task	Crew	Time/subtask	Total Time
Assemble, screw, and glue one structural sidewall	1 lead tech, 2 techs	0.5 hr	1 hr
Insert One Endframe in Module Assembly Fixture	1 lead tech, 2 techs	0.25 hr	0.5 hrs
Attach One Structural Sidewall to Endframes	1 lead tech, 2 techs	0.5 hr	1 hr
Attach one RPC Module to Rib or Sidewall	1 lead tech, 2 techs	0.5 hr	6 hr

References

1. ISO 1496-1:1990 *Series 1 freight containers – Specification and testing – Part 1: General cargo containers for general purposes*